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Description and Culture of Lentils

Abstract

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Lentils (*Lens culinaris* Medik.) are known to be one of the first plant species to be domesticated but have been poorly researched compared with many other pulse (grain legume) crops and, especially, the major cereals. Almost all of the few "cultivars" that have been released until now are selections from small collections of germplasm and not from hybridization programs. However, the advent of a large, multidisciplinary crop improvement program with a mandate for improving lentil production worldwide, and ongoing and strengthening regional and national programs in Argentina, Canada, Chile, Hungary, India, and the United States now provide resources for hydridization and research on a scale much greater than possible in the past. Nevertheless, many researchers are unfamiliar with the crop, and many farmers do not fully appreciate the constraints that must be overcome if yields are to be stabilized and improved. This publication describes various aspects of the crop, reviews the culture of lentils in the United States (the major exporting country) and worldwide, and advocates greater cooperation, collaboration, and communication among researchers, breeders, administrators, producers, and the industry in general.

Keywords: Lentils, *Lens culinaris* Medik., pulse crops.

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Description and Culture of Lentils

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Introduction

World and national average yields for all the pulse (grain legume) crops are only about one-half as large as those for all the cereals (table 1) and have either stagnated or, at best, have shown slower rates of increase in recent years. Record yields are also much smaller than those of cereals. To some extent, neither of these facts is surprising. Grain legume crops assimilate into seeds far larger concentrations of protein, and sometimes oil, than do the cereals, which store mostly carbohydrates.

From comparisons of the known energy requirements of various metabolic pathways, one gram of glucose can give rise to about 0.8 g carbohydrate but, on average, only about 0.5 g protein and even less oil. According to Penning de Vries et al. (*1974*),[2] equivalent seed yields would be about 70 units for soybeans, 90 for peas, and 100 for wheat and maize (Evans *1980*). Such large concentrations of protein (and hence nitrogen) in seeds may require early mobilization of protein out of leaves, thus impairing their capacity for prolonged photosynthesis. The maintenance of symbiotic dinitrogen fixation in root nodules requires prolonged use of photosynthate and thus may reduce the energy available for storage in seeds ([see] Minchin et al. *1981*). These energy requirements are especially critical for legumes because of their indeterminate growth habit and progressive flowering and seed setting compared with the synchronous flowering of cereals, and may be responsible for their reduced yield potential (Evans *1980*). Furthermore, the unfortunate fact that many farmers regard grain legumes as "secondary crops" means that they are often grown in marginal, arid areas where they are neglected agronomically and seldom benefit from fertilizer inputs, pest control, or irrigation, or are not planted until staple cereals have been established and weeded, or receive agronomic attention as a consequence of the methods used for other crops (Summerfield *1981b*).

The research and breeding efforts devoted to leguminous crops are minimal in comparison with those devoted to cereals. For example, while soybeans have probably been the subject of more research than all other grain legumes combined; in 1976 there were no more than 25 soybean

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[2]The year in italic, when it follows the author's name, refers to Literature Cited, p. 17.

Table 1.—*Area harvested, average seed yield, and production of selected cereal and grain legume crops in the United States and worldwide (from Food and Agriculture Organization), 1979*[1]

Crop species	Area harvested		Average economic yield		Production	
	United States	Worldwide	United States	Worldwide	United States	Worldwide
Cereals:	*Ha x 10⁻³*		*Kg/ha⁻¹*		*t x 10⁻³*	
Total[2]	67,978	760,896	4,402	2,041	299,257	1,553,076
Wheat	25,333	238,723	2,301	1,782	58,289	425,478
Rice (paddy)	1,206	145,268	5,142	2,615	6,199	379,814
Barley	3,024	97,746	2,724	1,761	8,238	172,175
Maize	28,726	120,540	6,865	3,271	197,208	394,231
Oats	3,979	26,759	1,950	1,604	7,757	42,909
Millet	([3])	53,879	([3])	620	([3])	32,962
Sorghum	5,240	50,879	3,947	1,322	20,684	67,268
Rye	384	14,798	1,624	1,602	624	23,705
Grain legumes:						
Total[2]	29,859	130,873	1,962	968	64,659	156,343
Dry beans	574	25,486	1,633	580	937	14,781
Dry broad beans	([3])	7,006	([3])	1,053	([3])	7,376
Dry peas	[4]74	10,500	[4]1,957	1,169	[4]144	12,269
Chickpeas	([3])	10,364	([3])	714	([3])	7,405
Lentils	[2]52	1,848	[3]1,136	583	[2]59	1,077
Soybeans	28,542	56,737	2,162	1,660	61,715	94,207
Groundnuts (in shell)	617	18,932	2,922	1,016	1,804	19,228

[1]See appendix B (and elsewhere in this publication) for the conversion of Imperial and other units to metric units and vice versa.
[2]FAO estimates (and see qualifying information in original publication).
[3]No information.
[4]Unofficial figures.

breeders in the United States (the major producing country) compared with the more than 400 maize breeders (Pendleton *1976*).

Notwithstanding the neglected research and crop status of grain legumes compared with cereals, remarkable progress in applied legume science has been made in recent years, especially in tropical regions and mostly due to the work of the international system of agricultural research centers (see examples in Summerfield and Bunting *1980*). Indeed, progress has been so rapid that the problem now is no longer one of "generating data" but rather of increasing the chance that a small proportion of data might prove useful to legume researchers in general and to breeders in particular (Summerfield *1981b*).

Though table 1 does not include imporant grain legume crops, such as cowpeas, pigeon peas, lupins, and a range of miscellaneous species of parochial importance around the world (for example, Rachie and Roberts *1974*), it serves to reflect the relative contributions of the major gramineaceous and leguminous crops to food production. Cereal production worldwide exceeds that of legumes by an order of magnitude: the cereals occupy almost six times more land and, on an average, are twice as productive (notwithstanding any differences in crop duration and the many problems that bedevil such simple comparisons; see Evans *1980*). Lentils (*Lens culinaris* Medik.) contribute about 2.5 and 5.3 percent, respectively, to the supply of edible pulse crops (the first legumes in table 1) worldwide and in the United States.

It is against this backcloth that we were motivated to compile this review on lentils, hoping to provide information not only useful to researchers who, perhaps, are not yet familiar with the species, but also to farmers so that they might better appreciate the problems involved with current efforts to improve and stabilize economic yields from the crop.

Background

Production of Lentils and Other Pulse Crops in the United States

Production of the so-called pulse (grain legume) crops—namely, dry edible beans, peas, and lentils—has been estimated to contribute about 1 percent of the total farm income derived from U.S crops (that is, an average of about $390 million per annum from 1973 to 1978). Furthermore, since just 10 States now produce more than 98 percent of the total (table 2), the contribution of pulse crops to regional economies is even more impressive: about 10 percent of farm income is derived from pulse crops in Michigan, about 6 percent in Idaho, and about 5 percent in Colorado (Smith *1980*). Although total production has changed relatively little during the past 20 years, the reasons underlying this apparently stagnant situation have been far from static. Some States have maintained fairly constant production; some have declined to such an extent that they are no longer considered to contribute to the national output; while others have increased production by more than 300 percent (table 3).

Table 2.—*Average total pulse production by State (ranked according to output) for successive decades in the United States (calculated from Smith* 1980*)*

State	Production		Rank	
	1957-68	1967-78	1957-68	1967-78
	t x 10⁻³			
Michigan	338	306	1	1
Idaho	167	171	2	2
California	146	140	3	3
Washington	129	138	4	4
Colorado	93	87	5	6
Nebraska	61	89	6	5
New York	57	28	7	8
Wyoming	42	24	8	9
Montana	10.5	7.7	9	11
North Dakota	8.5	41	10	7
Kansas	7.6	7.4	11	12
Oregon	6.9	0	12	([1])
Minnesota	4.6	19	13	10
New Mexico	3.2	0	14	([1])
Utah	2.2	2.9	15	13
Total	1,076.5	1,061.0		

[1]Not applicable.

Table 3.—*Changes in the land area cropped to pulses, the number of farms involved, and the average area per farm between 1964 and 1974 in the major pulse-producing States in the United States (calculated from Smith* 1980*)*

State	Area sown to pulses		No. farms involved		Average area per farm	
	1964	1974	1964	1974	1964	1974
	Ha x 10⁻³				*Ha*	
Michigan	239.0	192.0	12,931	6,900	18.6	27.9
Idaho	104.0	128.0	4,044	3,489	25,5	36.9
California	70.5	77.8	1,940	1,416	36.5	55.1
Washington	71.3	99.2	1,651	1,585	43.3	62.8
Colorado	67.6	70.9	2,318	1,588	29.2	44.6
Nebraska	25.5	40.5	1,515	1,344	17.0	30.0
New York	37.3	16.2	2,736	790	13.8	20.7
Wyoming	18.6	9.3	910	431	20.7	21.5
Montana	4.9	3.6	338	166	14.6	21.9
North Dakota	12.2	42.1	606	993	20.3	42.5
Kansas	2.4	3.2	91	84	26.7	38.5
Oregon	4.5	0	107	0	41.7	0
Minnesota	6.5	24.4	337	931	19.4	25.1
New Mexico	1.6	0	110	0	14.6	0
Utah	4.1	6.5	44	80	91.9	81.0
Total or average	670.0	715.0	29,678	20,013	28.9	39.1

Irrespective of the relative importance of the pulse crop farmed in different States, a general national trend since the thirties (typified by the data presented in table 3 for the decade 1964 to 1974) has been a decline in the number of farms involved and a concomitant increase in the average area of individual holdings (relative changes of approximately -32 and +57 percent, respectively; table 3). Of the leading four pulse-producing States (table 2), only in Washington has the number of farms remained fairly constant (a decline of just 4 percent), and in area they are approximately double the national average for pulse

production enterprises (63 and 39 ha, respectively). These farms (fig. 1), along with those in northern Idaho (an area of rolling hills, perhaps better known as the Palouse; that is, from 46° to 48° N and at elevations up to 600 m), produce almost all of the U.S. lentil crop (table 4), most of which is exported (table 5).

Cereal farmers in the Palouse are increasingly attracted to lentils for inclusion in their crop rotations for a number of reasons: (1) Susceptibility to disease, insects, and environmental stress has contributed to a decline in the area sown to peas; (2) the benefit of a legume in a crop rotation in terms of soil erosion control (the legume replaces summer fallow, a practice which is known to increase the probability of severe erosion); (3) less severe disease infestations in cereals because the legume is not an alternate host for some cereal pathogens; (4) better control of grassy weeds compared with cropping systems with only cereals in the rotation; (5) diversification to exploit the symbiotic association with *Rhizobium* and so to decrease consumption of expensive inorganic fertilizers; and (6) broader market opportunities because of increased demands in domestic and foreign markets. Accordingly, the

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Figure 1.—Rolling hills typical of farmland in the Palouse area of eastern Washington and northern Idaho.

Table 4.—*Production of lentils in the United States by State and proportion exported from 1967 to 1977 (modified from Smith* 1980, *and see table 9)*

Year	Production: Washington	Production: Idaho	Production: Total	Proportion of production exported	
	t x 10⁻³			*Percent*	*t x 10⁻³*
1967	23.5	9.0	32.5	84	27.3
1968	26.1	8.2	34.3	69	23.7
1969	30.7	9.8	40.5	79	32.0
1970	26.4	11.1	37.5	81	30.4
1971	35.7	12.2	47.9	78	37.4
1972	41.9	11.0	52.9	79	41.8
1973	34.1	9.8	43.9	53	23.3
1974	37.2	10.8	48.0	90	43.2
1975	52.1	15.2	67.3	71	47.8
1976	41.3	12.6	53.9	73	39.3
1977	10.5	4.6	15.1	63	9.5
1978	48.0	20.1	68.1	([1])	

[1]No information.

Table 5.—*Average and variability of lentil production and export by State and from the United States from 1967 through 1978 (modified from Smith* 1980)

State or National	Average production and export		Standard deviation	Coefficient of variation
	t x 10⁻³	*Percent*		*Percent*
Production:				
Washington	33.9	75	11.5	34
Idaho	11.3	25	3.8	34
Total	45.2	100	14.8	33
Export (USA)	32.3	72	11.0	34

area sown to lentil crops in the Palouse has almost doubled in the 3 years from 1978 to reach 92,000 ha in 1980, although average seed yields have remained about the same (about 1 300 $kgha^{-1}$).

A single cultivar (or, more correctly, a partially selected land race), 'Chilean', dominates commercial production in the Palouse; it is a yellow cotyledon type as compared with the smaller seeded Persian types which have red cotyledons and are grown principally in the Mediterranean region and Middle East. The crop is normally seeded in April, after the danger of severe frosts is slight, and matures within 120 days. Almost all the current production area is rain fed (though the potential for irrigated lentil crops in this area is not precluded), and as much as 80 percent of the cropland slopes from 8 to 30 percent (Papendick and Miller *1977*).

The delineation of pulse production areas is not based on State boundaries but on similarity in climate, weather, and cultural practices. Thus, lentil production may be possible in areas such as northwest Montana; east North and South Dakota; and perhaps even northern Minnesota (Robinson *1975*). Whether production expands into these areas will depend on the attitudes of producers, the availability of farming machinery and equipment appropriate for the crop, and the relative profitability and certainty of return from lentils compared with alternative crops.

Whether grown on the large-scale enterprises that characterize Palouse production or on much smaller farms (perhaps a tenth of the area or much less) in Middle Eastern or Mediterranean countries, optimum lentil production depends on a careful consideration and prudently selected combination of cropland, seedbed preparation, pest control, and timeliness and method of harvesting. Notwithstanding the farming acumen of producers, lentils are sold into traditionally volatile markets; informed and astute marketing strategies are likely to feature strongly in the overall profitability of the crop (Smith *1980*; Young et al. *1981*).[3] Lentil exports vary in direct relation to production (table 5) and, similar to other U.S. pulses produced largely in a single area, production depends to a large degree on the prevailing weather (see, for example, the disastrous consequences for lentils of the atypically hot and dry year in 1977, table 4). As table 5 shows, lentil production and, therefore, exports are erratic with average variations of ±33 percent of the respective means. As in other grain legume crops, lentil yields are acutely sensitive to the vagaries of weather and climate (see Summerfield and Wien *1980*). The challenge to plant breeders, and to those researchers who support their efforts, is not only to improve but also to stabilize lentil yields in different locations and cropping seasons (see Summerfield and Muehlbauer *1981*)—and then not only for the sophisticated agronomic systems practiced on large Palouse farms (table 3) but also for traditional farmers elsewhere (for example, Gibbon *1981*).

The International Lentil Scene

American producers—those familiar with the crop (or, at least, with cultivar 'Chilean') and accustomed to yields more than double those achieved in many other countries (table 1)—may be surprised to learn that there had been no global, regional, or even national studies of the trends in lentil production or the reasons underlying these trends until the appraisal by Watson (*1981*) of the current international status and future potential of the crop and by Smith (*1980*) of the future role of cooperatives in marketing pulse crops in the United States. World production increased by 1.1 percent per annum between 1963 and 1978, due both to slight increases in total area sown to the crop and in overall yield per unit area. Individual countries, however, differ markedly in these respects (table 6), from dramatic increases in area, or yield, or both (for example, Argentina) to equally dramatic declines (for example, U.S.S.R.). Then again, increased production may have been entirely absorbed by domestic markets (as in India) or a large proportion exported, as from the United States (the world's largest exporter of the crop).

[3]Young, D. L., R. C. Mittelhammer, and R. L. Sargent, 1981. Evaluating, marketing, and storage strategies for Washington and Idaho dry pea and lentil growers. Washington and Idaho Dry Pea and Lentil Commissions mimeographed report. [Unpublished.]

Table 6.—*Production, area, and average seed yield of lentils in various countries (from Food and Agriculture Organization* 1978 *and Watson* 1981)

Country	Production		Area in	Seed yield in	Relative change— In area from 1961 to 1965[1]	Relative change— In yield from 1975 1977[2]
	1961/65[1]	1978	1978	1978		
	t x 10^{-3}		*Ha x 10^{-3}*	*$Kgha^{-1}$*	*Percent*	
India	348	434	927	449	+ 18.7	+ 8.9
Turkey	94	260	240	1083	+ 59.2	+16.9
Syria	64	92	136	679	+ 78.5	- 6.3
Yugoslavia	1	61	77	791	0	0
United States	25	58	51	1125	+100	+ 2.0
Bangladesh	46	50	75	658	0	+ 2.1
Argentina	11	40	55	734	+ 7.2	+95.0
Ethiopia	95	33	63	533	- 40.1	- 1.5
Pakistan	35	32	80	400	- 9.8	-14.5
Iran	39	25	35	714	- 25.4	+ 3.1
Morocco	12	21	37	568	+ 92.0	+21.5
Chile	13	19	32	595	0	+30.8
Egypt	50	16	15	1073	- 15.2	- 3.4
U.S.S.R.	90	15	20	750	- 62.3	-14.5

[1]Average values of a 5-year period.
[2]Average values of a 3-year period.

As Watson (*1981*) so cogently argues, annual production statistics have many well-known shortcomings, and averages from selected successive years can better reveal long-term trends. The information presented in table 6 illustrates his thesis.

Cryptic reports describe lentils as grain legumes "well-adapted" to cool conditions: they are normally seeded after autumnal rains in India and Pakistan and grow throughout the winter (rabi) season. The crop is reported to be intolerant of extreme heat and cold, which may explain why it is confined to higher elevations in tropical countries such as Ethiopia and Mexico or is grown in the spring at high elevations in temperate countries such as Iran and Turkey. The crop is also said to tolerate drought far better than waterlogged soils. Indeed, a large proportion of lentil crops is grown in rain-fed agricultural systems or depends on water conserved in the soil. The distribution and frequency of rainfall are major determinants of productivity (Sinha *1977*).

Lentils are grown on sandy loam soils (where irrigated crops and/or short duration cultivars may produce large yields), on alluviums, on black cotton soils, or on much heavier substrates. Some crops are grown in moderately alkaline conditions or in saline soil, and many are rooted in soils poor in phosphate. In such situations, genotypes can respond favorably to appropriate fertilizer applications, although excessive P concentrations can induce zinc deficiency, one of the few trace element deficiencies reported for the crop (see citations in Summerfield *1981a*).

From the meager data available, which are probably for crops that produced only poor yields, symbiotic dinitrogen fixation by lentils has been estimated at between 35 and 77 kg $Nha^{-1}annum^{-1}$ (Nutman *1969*). For an average seed yield of just 600 $kgha^{-1}$, which is probably close to the world average (table 1), and with a mean protein concentration of 25 percent, a lentil crop that matures in 120–150 days from sowing would produce 150 kg protein ha^{-1}. This represents 24 kg Nha^{-1} in seeds alone, which, if the estimates of annual fixation are realistic, shows clearly how an "average" lentil crop could deplete soil nitrogen status. This largely negates the assumed beneficial role of a legume in cropping rotations! Other reports (see Summerfield *1981a*) however, cite values as large as 103–115 kg Nha^{-1} for symbiotic fixation by lentil crops in Egypt and the United States (but make no mention of the time required to achieve these amounts or how they were calculated). In India, the fertilizer needed by a maize crop can be reduced substantially if the preceding crop is either lentils, chickpeas, peas, or *Lathyrus sativus* L. rather than wheat or, indeed, winter fallow (Ahlawat et al. *1981*). Clearly, cultural and agronomic practices that enhance the seasonal fixation activity of symbiotic associations well adapted to their aerial and edaphic environments need to be identified. Studies towards this end merit some priority in lentil improvement programs such as those devoted to larger yields from Palouse crops.

Lentils are reported to produce seed yields as large as 3 500 $kgha^{-1}$ (Sinha *1977*), but as tables 1 and 6 show, farmers are seldom so successful. Even in the sophisticated production systems practiced in the United States, a yield of 1 800 $kgha^{-1}$ would be considered exceptionally large.

Taxonomical and Historical Perspectives

Lentils are known botanically as *Lens culinaris* Medik. and then by at least 30 other common names in various parts of the world (Kay *1979*). *L. culinaris* belongs to the order Rosales, suborder Rosineae, family Leguminosae, and subfamily Papilionaceae. Within the Papilionaceae, *Lens* occupies an intermediate position between *Vicia* and *Lathyrus*, but it is more closely related to *Vicia*. The genus *Lens* contains the cultivated lentil, *L. culinaris* Medik. (synonym *L. esculenta* Moench.) and four wild species: *L. ervoides* Brign., *L. montbretii* Fisch and Mey., *L. nigricans* Bieb., and *L. orientalis* Boiss. (Williams et al. *1974*). Synonyms for the wild species have appeared in the literature, but they are too numerous to mention here. Similarities in plant type and pollen-grain morphology suggest that *L. culinaris* was derived from *L. orientalis* (Zohary *1972*, Williams et al. *1974*). *Lens culinaris* is diploid, with 2n = 14 chromosomes, as in *L. orientalis* and *L. nigricans*. Chromosome numbers have not yet been reported for *L. ervoides* or *L. montbretii*.

The behavior of *L. culinaris* x *L. orientalis* F_1 hybrids and the segregation patterns of F_2 populations indicate that pod indehiscence (that is, tendency to achieve harvest ripeness without shattering) of the cultivated type is governed by a single recessive gene (Ladizinsky *1979b*). Thus, it seems that domestication of lentils occurred as a result of human selection of a spontaneous indehiscent pod mutant from *L. orientalis*, negating the need to harvest immature pods to avoid loss of seeds (Ladizinsky *1979c*).

The presumed wild progenitor of cultivated lentils, *L. orientalis* (Ladizinsky *1979a*), inhabits dry, coarse-textured, stony hillsides (fig. 2) in the Middle East in proximity to where lentil crops are grown by traditional farmers. Indeed,

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Figure 2.—Typical habitat of the wild relatives of cultivated lentils.

in many countries of the Middle East and nearby Mediterranean areas, lentils are cultivated on marginal lands where the crop is subject to drought and must compete with pests, pathogens, and weeds (Summerfield *1981a*), conditions more like those encountered by ancestral relatives rather than production practices in the Palouse.

Lentils were probably one of the primary domesticates (as were wheat and barley) upon which neolithic agriculture was founded in the Near East about 8,500 years ago. By the Bronze Age, they had been widely disseminated throughout the Mediterranean region, Asia, and Europe (Youngman *1968*, Zohary *1972*, Renfrew *1973*, and Hubbard *1980*). The crop was probably introduced into the Palouse soon after the turn of this century (in 1916 according to Youngman *1968*). The vast commercial area sown to the crop today can probably be traced back to what, in reality, was a chance introduction of a single land race (perhaps via Europe).

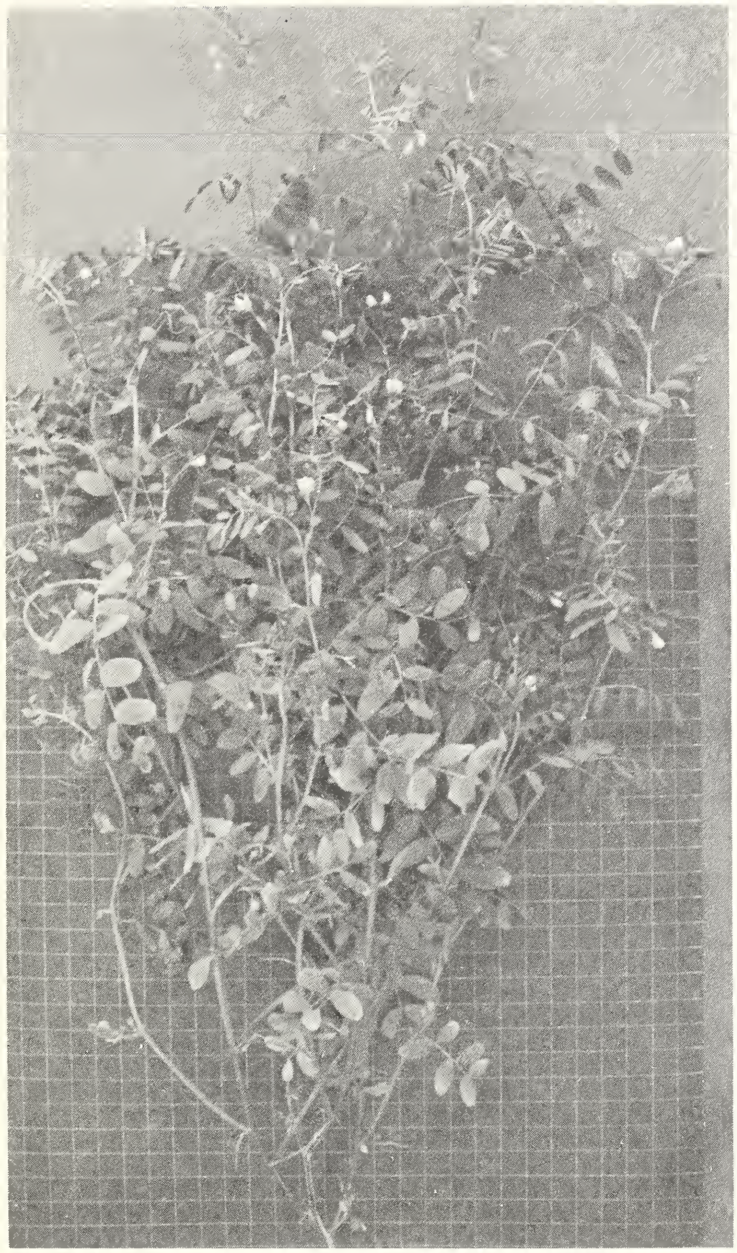
Successive generations of farmers have probably selected (consciously or otherwise) better adapted materials from within the original land race (for example, by saving seeds for subsequent crops from particularly productive fields), but compared with wheat, for example, cultivars with significantly greater yield potential have yet to make the transition from breeders' plots to farmers' fields. This is not surprising. Not only have breeders of wheat, and their teams of support scientists, been active for decades longer than lentil researchers, but also current breeding efforts for wheat probably outnumber those in lentils by a factor of at least 20:1 in the Pacific Northwest alone.

Lentil Description and Culture

Description

Lentils are slender, semierect annuals usually between 30 and 75 cm tall (fig. 3), but if flowering is delayed and/or crop durations are extended by, for example, cool temperatures, their indeterminate habit (that is, they do not initiate flowers at stem apices) can result in excessively tall plants. The crop is remarkably plastic and many cultivars will branch profusely, depending on crop density. Individual plants may vary from single stems to vigorous, bushy forms in dense or sparse stands (see Wilson and Teare *1972*).

The leaves, like those of chickpeas, are relatively small compared with soybeans and *Phaseolus* beans. They are described as pinnate or imparipinnate and comprise perhaps as many as 14 sessile, ovate or elliptic or obovate or lanceolate leaflets each about 1 cm long. Each leaf is subtended by two small stipules and may or may not



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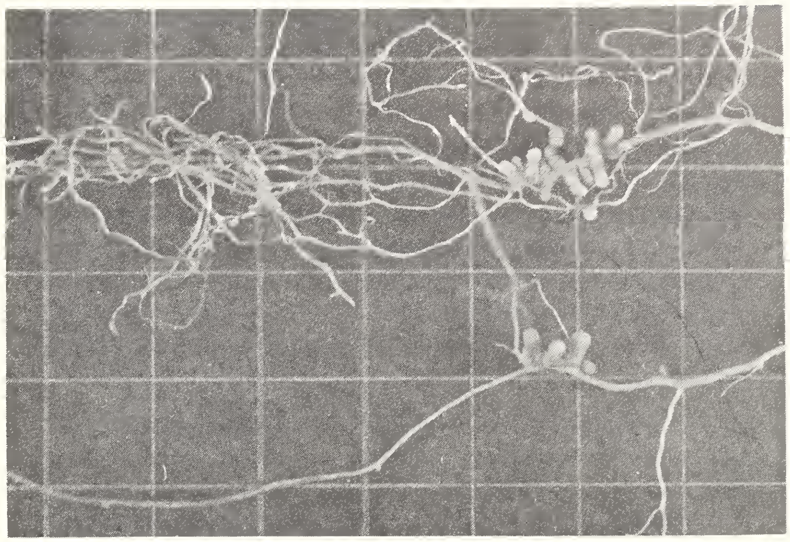

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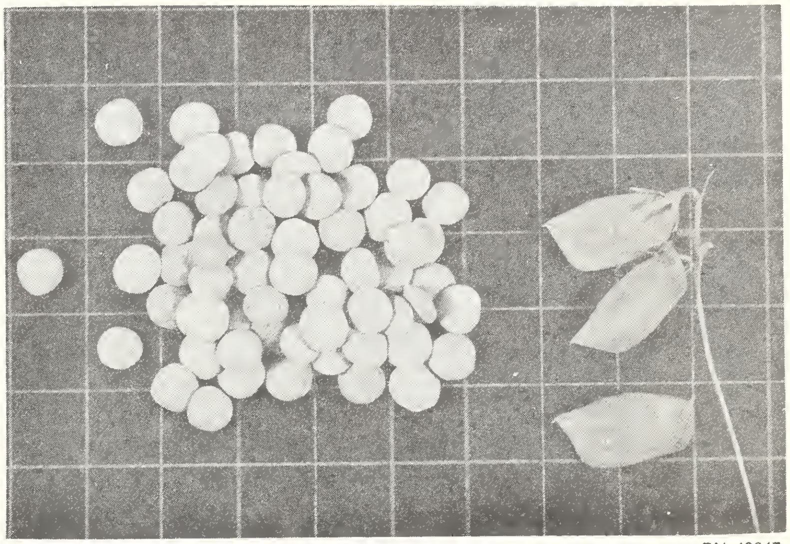

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Figure 3.—Morphology of lentil cv. 'Chilean': fruiting shoot system of a well-spaced, pot-grown plant 85 days after sowing (left); nodulated secondary roots from the same plant (top right); and immature fruits and ripe seeds (bottom right). Lines are a 1 cm^2 grid.

terminate in a tendril. The photosynthetic capacity of lentil leaves seems neither greater nor less than other (more productive) grain legumes, is equally variable and presents the same problems for measurement and interpretation of comparative data. It seems unlikely that selection for "photosynthetic rate" would be a worthwhile objective for lentil breeders as some have suggested (Summerfield *1981b*).

Reproductive nodes bear either single flowers or two or three but rarely four-flowered racemes on short peduncles, although Hawtin (*1977*) has recorded seven flowers per peduncle on one selection from Afghanistan when grown in a glasshouse. The typical Papilionaceous (butterflylike) flowers are small (4 to 8 mm long); white, pale purple, or purple-blue; and usually open before 10.00 h on cloudless days but perhaps not until 17.00 h when the sky is overcast. The corolla petals fade within 3 days, and fruits (usually referred to as pods) are visible 3 to 4 days later (Hawtin et al. *1980*, Summerfield *1981a*). The oblong pods are flattened and smooth, about 1 to 2 cm long, and usually contain one or two but rarely three seeds (fig. 3). Some researchers find it convenient and useful to adopt the classification of Barulina (*1930*) who divided lentils into two types.

1. *Macrosperma*, which are found mainly in the Mediterranean region and the New World, have large seeds (6 to 9 mm in diameter), normally yellow cotyledons, and little or no pigmentation in the flowers or vegetative structures. Both cultivars 'Chilean' and 'Tekoa', familiar to Palouse farmers, would be classified into this group; and

2. *Microsperma*, which are found mainly in the Indian subcontinent and parts of the Near East, have smaller seeds (2 to 6 mm in diameter) with red, orange, or yellow cotyledons. Cultivars in the *microsperma* are more polymorphous as a group but are generally shorter and more pigmented and have smaller pods, leaves, and leaflets than *macrosperma* types.

In general, lentil seeds are lens shaped (biconvex) and weigh between 2 and 8 g per 100 (fig. 3). Testa colors range from light tan to brown and black; purple and black mottling and speckling of seeds are common in some varieties and germplasm accessions (Duke *1981*). The seeds are rich in

protein (concentrations between 22.4 and 34.6 percent were found by Hawtin et al. *1977* who evaluated 1,688 accessions), which, as in other grain legumes, is limited in nutritional value by the small concentrations of the sulfur-containing amino acids, methionine and cystine (Summerfield *1981c*). Improved genotypes may not only yield more protein than current commercial cultivars, they may also assimilate seed proteins of better quality (for example, 'Brewer', soon to be registered and released, originating from a 'Tekoa' x *Lens nigricans* Bieb. cross by A. E. Slinkard in 1969 and developed as a pure line from an F_4 selection by F. J. Muehlbauer).

We concur with Boulter (*1980*) that while larger supplies of grain legumes protein are most likely to result from increased and stabilized yields of seed rather than improved seed biochemical efficiency, since the energy required is approximately the same for synthesizing proteins with good or poor amino acid profiles (Boulter *1977*), improvements in protein quality seem distinctly possible. If the seeds are for human consumption, a smaller concentration of protein of improved quality may be a better breeding objective tnan a larger concentration of protein of poorer quality. Whether this is so will depend not only on the magnitude of economic yield and its price, but also on the presence of antimetabolites, flatus factors, and other attributes that determine how much consumers are willing to eat. The current status and future potential of lentils as a diverse food source for various ethnic groups have been reviewed and discussed by Leung and Salunkhe (*1981*). In the future, larger and more reliable supplies of the crop will be needed for traditional diets, novel snacks, fortification of protein-deficient foodstuffs, and so on.

Numerous data on protein concentration and quality in lentil seeds have now been assembled and will be described elsewhere (Summerfield and Muehlbauer, in preparation). However, variations due to crop location, year, and laboratory performing analyses seem to be equally as large, if not larger, than differences among cultivars grown at a given location for a specific period and then analyzed by a single technique in the same laboratory (that is, useful genetic variation may be limited). For example, large variations in amino acid spectrum probably reflect considerable effects of different analytical methods rather than useful, heritable variations. Whether the sulfur-containing amino acids are protected from destruction (to a greater or lesser extent) during acid hydrolysis by prior oxidation of methionine to methionine sulfone and of systine to systeic acid, using performic acid could explain a significant proportion of the respective variations in these traits, which have been described in the literature (Summerfield *1981c*). At present, the lentil breeder cannot expect to include "desirable culinary aspects" among his or her principal selection criteria with any certainty of return. Attention should focus on increasing economic yield and on the stability of yield between sites and years.

Flowering in lentils proceeds acropetally; lower nodes may bear pods close to maturity while younger nodes are still initiating flowers. The flowers are naturally, self-pollinated; cross pollinations, vectored by thrips or other small insects, but not by wind or honey bees, are estimated to be less than 0.8 percent (Wilson and Law *1972*). In general, cold temperature vernalization of seeds, warming air temperatures, and lengthening days promote early flowering, but we have only a cursory understanding of the relative importance of these responses (for example, see Saint-Clair *1972*) and their significance in the adaptation of lentils to different agroclimates (see detailed discussion in Summerfield *1981a*).

Lentil seeds are more susceptible to mechanical damage than field peas, field beans, lupins, and chickpeas. Their composition varies with genotype and location; it changes as the seeds mature and is influenced by the availability of various inorganic nutrients (see citations in Summerfield *1981a*). Differences in seed composition are known to affect the cooking time of mature seeds.

Germination is described as hypogeal (the cotyledons remain below ground), which could mean that seedlings are less likely to be killed by freezing, wind or insect damage, grazing, or toxic doses of agrochemicals than if germination were epigeal (cotyledons raised above ground level as the seedlings grow—as in soybeans.) If young lentil shoots are damaged, new buds can be initiated from nodes below ground. Three types of root systems have been described and related to soil type, branching pattern, and seed size (Kay *1979*). The agronomic relevance of these observations has yet to be established (Summerfield *1981a*).

Lentils are infected with the same species of *Rhizobium* (*R. leguminosarum*) capable of nodulating peas and field beans (broad beans; *Vicia faba* L). The nodules are indeterminate, elongate, and sometimes branched, with an apical meristem; they seldom exceed 5 mm in length (fig. 3 and Sprent *1980*). Lentil crops may or may not respond favorably to artificial inoculation, depending on the previous cropping history and soil type in a particular location and the concentration of inorganic nitrogen available to the crop.

As we have stressed earlier, lentil crop improvement programs must include "symbiotic potential" among selection criteria. Breeders will need to select for nodulation and dinitrogen fixation, which means they will need to know the ecology of *Rhizobium* in their breeding plots and to restrict applications of inorganic fertilizers to them. It may also be prudent to rotate the locations of lentil breeding plots with those of the cereal breeder. If these criteria and practices are neglected, the symbiotic potential of lentils could decline in proportion to the breeding effort put into the crop (see Summerfield *1981b*).

Information on genetics and breeding methodology and a description of hybridization techniques in lentils can be found in Muehlbauer and Slinkard (*1981*) and in Muehlbauer et al. (*1980*), respectively.

Land Requirements

Palouse lentil crops are usually sown in the spring in rotation with winter wheat or barley. A common practice is to follow lentils with winter wheat because the land is usually in excellent condition after the legume crop. Moisture removed from the soil by the lentils is usually fully replenished by fall and winter rains; therefore, subsequent wheat yields are not depressed. Indeed, it it generally accepted by farmers that wheat yields following lentils are similar to those following peas.

Lentil crops in the Palouse yield the most when grown on well-drained soils on south and east facing slopes. Hilltops and ridges may lack sufficient soil moisture, particularly during the seed-producing stage of development. Seasonal fixation profiles by *Rhizobium* bacteria may also be significantly poorer on ridgetops than on sloping lands, especially, deep, well-drained bottom lands (Mahler et al. *1979*). Crops grown on draws and flats can yield well, but these areas often remain wet until late spring, which delays sowing, restricts crop duration, and, for current cultivars, depresses yields. Furthermore, crops seeded in such locations will often produce excessive vegetative growth at the expense of economic yield (though the reasons why are poorly understood). Therefore, it seems prudent to avoid wet draws and flats for lentil culture wherever possible.

Seedbed Preparation

Palouse farmers are recommended to plow or disk their fields intended for lentils in the fall or early spring to incorporate previous crop residues (Entenmann et al. *1968*). Tillage along the contours of hills improves moisture retention and prevents excessive runoff and soil eroision (Papendick and Miller *1977*). In the spring, when soils are sufficiently dry, fields should be cultivated and firmed with a spring tooth harrow (fig. 4), although some growers prefer to use a rod weeder. Deep tillage should be avoided; it

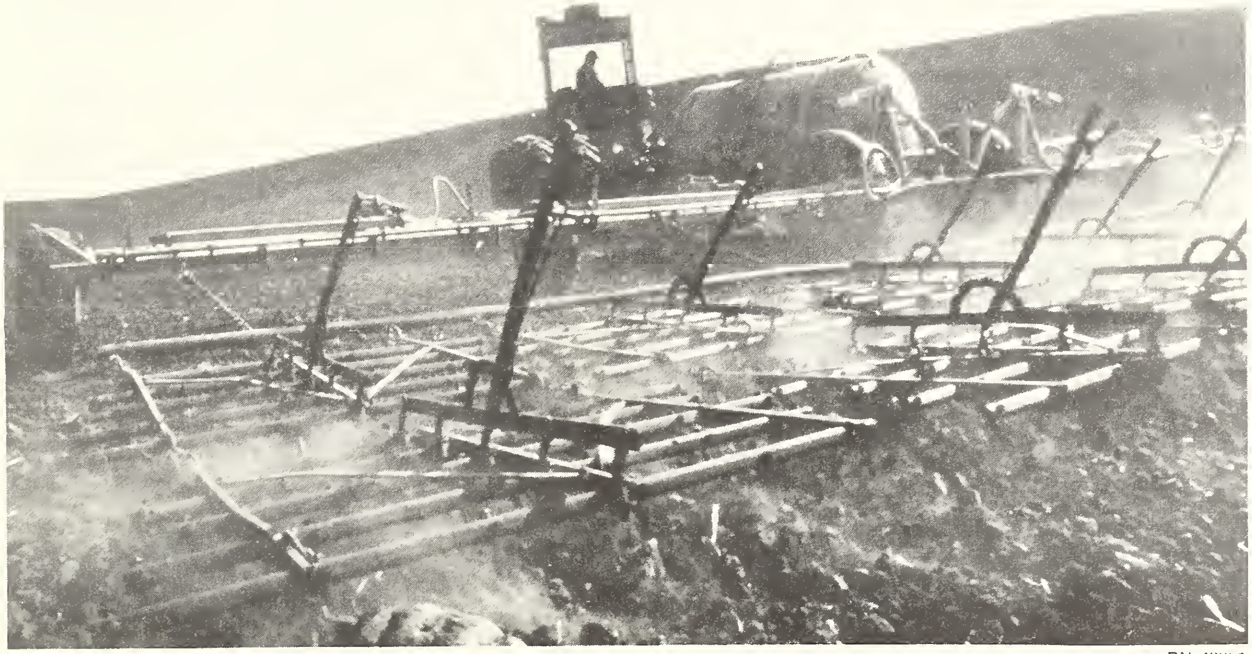

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Figure 4.—Preparing (above) and sowing into (below) a seedbed for lentil crops in the Palouse.

results in excessive moisture loss. Well-prepared seedbeds have a minimum crop residue on their surface (fig. 4). Soil temperatures warm quickly under cleanly tilled surfaces, thus, the respective rates of germination, emergence, and seedling growth are improved.

Seeding

Lentils are often planted with the same equipment used to seed cereals and then as early as possible in the spring to achieve maximum yields. Late seeding usually restricts vegetative development and allows only a brief flowering period; seed set is also invariably poor. Experience in the Palouse is typical of that elsewhere, irrespective of the period of the calendar year during which the crop is cultivated; namely, yield advantages due to early planting can be substantial (for example, Sharma *1970*; Hawtin et al. *1980*), providing seeds are not "puddled in" by excessive rainfall.

A soil covering sufficient to produce a weight of at least 3 g above individual lentil seeds is indispensable for root penetration and subsequent successful crop establishment (Kislev et al. *1979*). Many studies have indicated that a sowing depth of 4 to 5 cm is optimal for seedling growth, but in dry soils deeper placed seeds may not only be in a better microenvironment from which to imbibe water but may also be somewhat protected from frost. While some growers have been successful with deeper planting, others report poor emergence because of soil crusting following heavy rains (and/or compaction by farm machinery).

Rates of germination, emergence (hypocotyl elongation), and early seedling growth depend markedly on temperature. Lentil seeds can germinate throughout a wide range of temperatures whether in the light or darkness or in constant or diurnally fluctuating regimes (see citations in Summerfield *1981a*). The optimum temperature range varies with cultivar and the age and size of seeds; small seeds, which have a greater surface area: volume ratio than larger ones, can germinate more rapidly than larger ones at temperatures between 15° and 25° C.

There is no evidence that suggests that lentil seedlings must undergo any sort of "enforced dormancy" (or suspended animation) despite the common observation by farmers that lentil seedlings, once emerged, will often grow slowly, if at all, for days or even weeks. Rather, it is likely that successive stages of canopy formation (for example, stem elongation, leaf initiation, leaf expansion, and branching) have different "base temperatures" (that is, that temperature which is sufficiently cool to arrest a particular process). We suspect that the base temperature for leaf expansion, for example, is warmer than that for leaf initiation, and only when the seasonal increase of temperature exceeds these base temperatures can rapid growth occur. As yet, we do not know which aspect of the thermal regime of field crops (air or soil temperatures, day, night, or average temperatures) exerts the most influence on lentils.

Many studies show that lentil yields are remarkably stable over a wide range of population densities; the plants are able to fill available space by initiating lateral branches and can therefore compensate for poor emergence and thin stands. Recommended seeding rates for Palouse farmers are 56 to 67 $kgha^{-1}$ to give a plant population of 86 to 108 planst m^{-2} (Muehlbauer *1973*). Elsewhere seeding rates vary from 15 $kgha^{-1}$ in northern India to 110 $kgha^{-1}$ for irrigated crops in Egypt (see Hawtin et al. *1980*). However, it is always important to use seeds of good quality (that is, germination values of sample lots should be greater than 85 percent) and then a seeding rate large enough to ensure good stands if the crop suffers from adverse environmental conditions, resulting in poor percentage emergence and/or disrupted seed distribution. For example, Wilson and Teare (*1972*) reported an "optimum" population spacing of 15 by 1.5 cm (443 plants m^2), and in northern Syria a seeding rate of 160 $kgha^{-1}$ (15-cm row spacing) was needed for maximum yield of one *macrosperma* cultivar (Hawtin et al. *1980*). Rapidly warming springtime temperatures in northern Syria probably terminated the vegetative period while these plants were still comparatively small and so the space available was not filled except in the more densely planted stands.

Appropriate plant populations should be maintained in dryland farming systems. Although dense populations may intercept radiant energy more effectively than sparse stands, they may also deplete the soil profile of water more rapidly and eventually produce smaller economic yields (Fischer and Turner *1978*). This may not occur with short-duration cultivars, which, by maturing rapidly, may avoid substantial stress. Such a drought-avoidance strategy may explain why small-seeded (*microsperma*) lentil cultivars are considered to be more tolerant of drought than large-seeded (*macrosperma*) types in Bulgaria, (Ganeva *1969*). However, we know little about either agronomic practices (for example, seedbed preparation or crop density) or physiological mechanisms (for example, the preferential growth of roots at the expense of shoots, regulation of stomatal aperature, and changes in osmotic potential of leaf cells to maintain turgidity) that could contribute to the adaption of lentil crops to dry environments. We should use and benefit from experience with leguminous or other crops (for example, see Fisher and Turner *1978*, Wien et al. *1979*, and Bolton *1981*) in what is likely to be a priority area of lentil research.

We cannot begin to test predictions about the importance in the field of characters—such as rates of photosynthesis, heat tolerance of isolated tissues, water potentials, stomatal functioning, ability to accumulate abscisic acid, and so on (characters contributing to the ability of plants to grow and yield well in a droughty environment)—until drought resistant and nondrought resistant cultivars of lentil have been identified. (See the cogent discussions by Sheldrake and Saxena *1979*.) Researchers need to know the edaphic and environmental conditions in which lentil crops are grown by farmers in different regions and then to devise screening procedures that will give reliable indications of the performance of different genotypes in these conditions. Without doubt, the success of lentil as an internationally important crop depends greatly upon an improved ability to produce economically attractive and reliable yields when water supply is limited.

Compared with many edible grain legume crops of economic importance, lentils grown in the United States are relatively free from major disease problems. However, the most serious and ubiquitous disease problems concern the

root rot/wilt complex. Though the problem is far less researched than in chickpeas, data indicate seed should be treated with a fungicide to combat preemergence and postemergence damping-off caused by *Phythium, Rhizoctonia*, or *Fusarium* spp. One such fungicide, captan, marketed under several trade names, has proved effective. All fungicides should be used according to label instructions.

Lentil Cultivars

Notwithstanding the respectable antiquity and widespread distribution of lentils, few cultivars have been released to date, and of those that have been released, almost all are selections from germplasm and not from hybridization programs (Hawtin et al. *1980*). However, current national and international lentil improvement programs in Syria, India, Canada, Argentina, Chile, Hungary, and the United States now provide resources for hybridization and selection on a much larger scale than has been possible before. Each of these programs addresses the importance of collecting, exchanging, introducing, and maintaining germplasm to provide as wide a range as possible of genetic diversity upon which hybridization programs can be based (Muehlbauer and Slinkard *1981*).

Thus, with greater attention worldwide and with ongoing national and regionally supported programs, improved cultivars with larger yield potential (for example, 'Brewer' from Pullman) may soon impact commercial production.

In spite of progress projected for the future, three cultivars are currently recommended to growers in the Palouse, namely (1) 'Chilean' (a yellow cotyledon type), introduced into the region in about 1920 and has remained the principal cultivar grown to date; (2) 'Chilean 78', an improved Chilean type made available to growers in the spring of 1981. It comprises pureline selections from Chilean seed stock that were made to remove "off type" lentils and *Vicia* species from existing seed stocks. Yields are comparable to 'Common Chilean'; and (3) 'Redchief', a red cotyledon cultivar made available to growers in the spring of 1981. This cultivar has consistently outyielded 'Chilean' in yield trials over serveral years of testing, but the marketability of the red cotyledon types is, as yet, unknown.

Cultivars or, more correctly, selections from germplasm now recommended throughout the world, include 'Laird' and 'Eston' in Canada (Slinkard and Bhatty *1979*); 'L9-12', 'Pant L-209' and 'Pant L-406' in India; 'Giza 9' in Egypt (Hawtin et al. *1980*); and 'Precoz' in Argentina (Riva *1975*).

Fertilization and Pest Control

Fertilizers

Researchers have little idea of the nutrients required by lentil crops grown in the Palouse or anywhere else and, especially, of the demands of crops producing large yields. Based on experience around the world (see earlier discussions) advisers have considered it worthwhile economically, and a reasonable "insurance" for growers, to apply molybdenum (essential for good nodulation and dinitrogen fixation); sulfur (the concentrations in seeds of the nutritionally limiting S-amino acids can be improved in other legumes by applying S fertilizers; for example, see Fox et al. *1977*); phosphorus (again, essential for good symbiotic performance and overall plant growth); and, on occasion, potassium.

Application rates previously recommended to growers, and which we are reluctant to change until many more research data become available, have been as follows:

Molybdenum. Sodium molybdate at 35 gha^{-1} applied as a seed dressing.

Sulfur. Applied to the crop(s) grown in rotation with lentils at a rate of 17 to 22 $kgha^{-1}$ on deficient soils.

Phosphorus. In general, between 44 and 66 kg $P_2O_5ha^{-1}$ are applied if soil tests (acetate extract) reveal that available P concentrations are 4 parts per million (ppm) or less. Responses to P fertilizer are more common on severely eroded soils.

Potassium. Seldom deficient in Palouse soils but on sandy or severely eroded substrates an application of, say 22 kg K_2Oha^{-1} may prove beneficial (as in similar substrates in India), and also improve cooking quality of seeds (Wassimi et al. *1978*).

Nitrogen. Effectively nodulated lentil crops seldom respond to an application of inorganic N fertilizer (see earlier discussions). If crops are seeded early into cool, wet soil, however, a small starter dose, applied adjacent to but not in contact with seeds, may prove effective and circumvent the "nitrogen hunger" phase often experienced by grain legume crops before the advent of significant symbiotic dinitrogen fixation. Inoculation with an appropriate strain of *Rhizobium leguminosarum* is essential when lentils are seeded into new fields for the first time (or after a lapse of several years). In these circumstances, special care will be needed with seed dressings of fungicides potentially toxic to *Rhizobium* (for example, see Roughley *1980*).

Based on chemical analyses[4] of seed lots produced in the same year (1980) at the same location (Pullman; 46° 46′N), a lentil crop yielding 1000 $kgha^{-1}$ would remove from the soil, in the seeds alone, substantial amounts of P, K, Ca, Mg, and S (table 7). Depletion of soil N reserves will depend on the relative contributions of symbiotic dinitrogen fixation and uptake of inorganic sources. It will be interesting to compare these preliminary data with those for other lentil crops grown in a range of edaphic conditions and locations. For example, to produce 1,000 units of economic yield, do different cultivars need to assimilate into seeds similar amounts of these elements, or are there applicable differences in seed composition (either inherent differences or those due to genotype x environment interactions, or both)? Subsequent studies should also assess the role of lentil crop residues (hay) in maintaining long-term soil fertility status and as a feed for cattle (for example, see Gupta and Jayal *1965* and Jayal et al. *1970*). In the United States, lentil hay cannot be fed to cattle because herbicide tolerances have not been determined or approved (table 8).

[4]Plant and Soil Analytical Laboratory, Department of Plant and Soil Sciences, University of Idaho, Moscow, Idaho 83843.

Table 7.—*Estimates of the nutrients removed in lentil seeds for crops producing an economic yield of 1000 kgha^{-1}. Data for soybeans are included in comparison (Scott and Aldrich 1970)*

	Nutrients (kg1000 kg seeds^{-1})					
Crop	N	P	K	Ca	Mg	S
Lentil[1]	43	5.0	11.7	0.7	1.2	2.0
Soybean[2]	71	6.1	20.3	3.0	3.0	1.7

[1]Mean values for cultivars 'Chilean 78', 'Tekoa', and 'LC11981' (cv. 'Brewer').
[2]U.S. crops.
Note: All data were converted to elemental equivalents to facilitate comparisons.

Weed Control

Lentils are notoriously poor competitors with weeds (fig. 5), probably because crop growth rates are so small, especially in cool weather, during early vegetative growth. Inadequate weed control may reduce seed yield by as much as 75 percent, although the period of crop growth during which competition from weeds is most deleterious varies in different locations: 30 to 60 days after planting seems most critical in India compared with 60 to 90 days in Syria (see Hawtin et al. *1980*). Recent research has shown that a number of herbicide formulations are effective with lentils (for example, Drew *1978*), although for many subsistence farmers hand weeding or mechanical cultivation remains the principal method of control. Unfortunately, both these methods can damage lentil seedlings, increase the incidence of stem and root diseases, and expose even more weed seeds that can germinate and create additional problems later during crop life.

Harrowing lentils after seedling emergence is not recommended to Palouse farmers. Rather, research indicates the herbicides metribuzin and dinoseb amine effectively control annual broadleaf weeds (table 8). Note that the use of specified application rates for all products is critical to minimize crop damage. Excellent control has been obtained with preemergence surface applications onto roller-packed fields (fig. 5).

On occasion, heavy rains have leached metribuzin or dinoseb amine into the emerging lentil root zone, causing some seedling mortality. Crop injury (various degrees of leaf burning) sometimes occurs because of volatilization of dinoseb amine off the soil surface. In both situations, however, the plasticity of lentils has allowed surviving plants to branch and expand into available space, which minimizes yield losses from the cropped area.

Data show that wild oat can be controlled by triallate, diallate, and barban. Label instructions must be followed carefully in every case (table 8). Rates and timing of application are critical, and treated crop residues must not be fed to livestock.

2,4-D should not be applied onto, or near, lentil fields. It has proved extremely phytotoxic, and excessive crop injury is likely to occur.

Table 8.—*Herbicides for weed control in lentils cropped on the dryland areas of the Pacific Northwest (Peabody et al. 1981)*

Herbicide and target species	Application rate (Kgha^{-1} a.i.)	Method of application and comments
Wild oat:		
Triallate	1.4	Applied preplant or postplant and incorporated thoroughly into the top 5 cm of soil. Seed any time from immediately after, up to 3 weeks following, spraying. Do not graze livestock on treated area.
Diallate	1.4	Applied preplant or postplant and incorporated thoroughly into the top 3 cm of soil. Seed any time from immediately after, up to 3 weeks following, spraying.
Barban	0.37	Applied postemergence when wild oat are at the 1.5- to 2-leaf stage of growth and the lentils have fewer than 4 leaves. Do not feed lower 8 cm of stubble to livestock. Time of application is critical. Poor weed control may result if application is improperly timed. Do not use more than 56 to 112 Lha^{-1} water carrier.
Broadleaf weeds:		
Metribuzin	Consult labels.	Applied as a preemergence herbicide. Has contributed to lentil injury under extreme climatic (and volcanic) conditions.
Dinoseb amine[1]	2.5–3.4	Applied after seeding and rolling but at least 5 days before lentil emergence. Soil surface should be free from crop residues.

[1]Dinoseb amine is not listed in Peabody et al. *1981* but has been granted a Federal Insecticide Fungicide and Rodenticide Act (FIFRA), as amended, Section 18 (exemptions for Federal Agencies) Emergency Exemption from Registration for broadleaf weed control in lentils for the 1981 crop year. Registration or exemptions from registration for future crop years are, at present, uncertain.

Although Palouse farmers do not suffer the problem, Broomrape (*Orobanche crenata* Forsk. and *O. aegyptiaca* Pers.), an obligate parasitic angiosperm, can be very harmful on lentils grown in the Mediterranean and Near East region. Hand pulling is practiced occasionally, but, to date, no effective herbicide has been found. Basler (*1978*) reported that the tolerance for Glyphosate (a herbicide recommended in Egypt for *Orobanche* control in *Vicia faba* L.) is very poor and that this chemical cannot be used on lentils. Breeding for host plant resistance shows some promise as do the synthetic germination stimulants reported by Johnson et al. (*1976*).

Insects

Lentil crops are attacked by a number of pests wherever and whenever they are cultivated; the most common cited depradations (for example, see Hawtin and Chancellor *1979* and Singh et al. *1978*) are due to pod borers (*Etiella zinckenella* Treitschke), aphids (*Aphis* spp.), weevils (*Sitona*

lineatus L.), bruchids (*Bruchus* spp.) and cutworms (*Agrotis* spp.). Insect problems are not confined to the field; they can continue during storage. Indeed, lentils taken from archaeological sites in Egypt have revealed the same degree of infestation and by a member of the same Bruchidae genus as could be expected today (Southgate *1978*).

Several insect pests have been known to cause economically significant damage to lentil crops in the Palouse; pea aphids (*Acyrthosiphon pisum* Harris), cowpea aphids (*Aphis craccivora* Koch), thrips (*Megalurothrips* spp.), seedcorn maggots (*Hylemya platura* Meigen), and wireworms (*Limonius* and *Ctenicera* spp.) are the most

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Figure 5.—Preemergence surface application of herbicides for weed control in Palouse lentil crops (above), and the consequences that can result if weeds are not controlled effectively (below).

commonly recorded pests. *Lygus* bugs may also be more important than previously suspected. Many of the insect pests known to attack lentil crops in the Palouse are common in alfalfa fields from whence they migrate when the crop is harvested.

Aphids. Severe infestations cause plants to be variously stunted, deformed, and barren (that is, flowers and fruits are dropped prematurely). Aphids also transmit viruses from clover, alfalfa, and other legumes growing near lentil fields. Pea enation mosaic virus, pea streak virus, and various mosaic viruses are known to be vectored in this way. Research indicates effective control of aphids on lentils can be achieved by applying malathion at the rate of 1.12 kg a.i. ha^{-1}. Some systemic products, such as disulfoton and dimethoate, which may be more effective, are not yet registered for use with U.S. lentil crops.

Thrips. These insects have mouth parts capable of rasping and sucking. They damage lentil plants by rasping buds, flowers, and leaves and sucking the exuded juices. Typical symptoms of thrip damage are distorted and discolored flowers, white streaking and mottling of leaves, and brown streaking of the pods. Damage from thrips is generally not considered serious enough to warrant the use of insecticides for control. Chemicals used to control other insect pests of lentils will concurrently reduce thrip populations.

Seedcorn maggots and wireworms. These soil-borne insects attack lentil seeds soon after planting, or the stems and roots of seedling plants, or both. Stand losses can be severe. Control is limited to seed treatments with lindane (used according to State label directions).

Lygus. Two species are common in the Pacific Northwest (*L. hesperus* Knight and *L. elisus* Van duzee), and both are established pests of alfalfa grown for seed (for example, Hagel *1978*) and grain legumes, such as snap and lima beans, cowpeas, soybeans, and peas. Irrespective of the crop infested and the species of *Lygus* responsible, typical depradations include localized wilting, necrosis, and malformation of tissues; abnormal morphology because of damage to stem apices; abscission of reproductive structures (notably unopened buds, open flowers, and immature fruits); and deformations of fruits, or seeds, or both (for example, Gupta et al. *1980*). Infested crops may suffer a loss of economic yield, or a loss in product quality, or both.

The damage to lentil seeds, known colloquially as 'Chalky Spot' is, we suspect, caused by *Lygus* bugs (Summerfield et al. *1982*).

Diseases

As mentioned earlier, the most serious and ubiquitous diseases of lentil crops throughout the world are those organisms comprising the root rot/wilt complex (that is, *Pythium, Rhizoctonia*, *Fusarium*, and *Sclerotium* spp.; see citations in Hawtin et al. *1980*). Though generally not a serious problem in the Palouse, some damping-off of seedlings may occur in cool, wet soils. Data indicate seed treatment with the fungicide captan (used according to label instructions) gives effective control. Elsewhere, lentil rust (*Uromyces fabae* Pers.), downy mildew (*Peronospora lentis* Gäum.), and a number of viruses have been reported to attack the crop. The latter remain the major disease problem for Palouse producers. At present, the best assurance of control is to monitor diligently those insects known to vector the viruses (for example, aphids) and to ensure the timely application of insecticides.

Harvesting and Marketing

Harvesting

Harvesting frequently poses serious problems and represents a major constraint to lentil production in many traditional farming systems. To avoid loss of seeds due to shattering (fig. 6), many farmers will pull the crop by hand before it is completely dry (fig. 6), a practice which would not be considered economical in U.S. production systems. Short plant stature, tendency to lodge, and prevalence of stony soils have combined to discourage mechanization of lentil production on many traditional farms. To facilitate mechanization in these situations, the development of cultivars with tall, erect, nonlodging growth habits and nonshattering of pods is a major breeding objective in many programs.

Palouse farmers will generally harvest their lentils by mowing and swathing, (fig. 6), although some growers combine the crop directly. The plants are usually swathed when pods turn a cream-golden color, by which time some of the older pods will be dry and their seeds firm. Harvesting prematurely does not allow the seeds to fully mature within the pods; harvesting too late, when the pods are dry and brittle (overripe), can cause them to shatter and so to release their seeds onto the soil surface. Pod shatter can be minimized by mowing at night or early in the morning when relative humidities are high and dew deposits keep the pods supple. Should swathed lentils receive excessive moisture (rain), or if they have been cut prematurely, the windrows need to be turned to allow even drying and to prevent excessive fungal attack and spoilage.

Swathed lentils can normally be combined 10 to 14 days after mowing. Farmers use the same equipment as they do for cereal crops. A pickup attachment (pea bar) is needed to lift the plant material from a windrow into the machine. For successful combining, seeds should be hard (a useful subjective test in that hard seeds will not dent when bitten) and cylinder speed and concave spacing should be adjusted so that the seeds do not crack or break during threshing. Airflow rates should be adjusted to blow out chaff but not the seeds.

Lentil crops should not be combined when they are wet; the feeding mechanism to the cylinder and perhaps the cylinder itself are likely to clog, harvesting will be slowed, and threshing will be poor.

Machine groundspeed should be maintained close to 2.5 kmh^{-1}.

Marketing

Palouse lentil crops are graded according to U.S. standards that consider the prevalence of damaged and defective seeds and contamination by foreign materials in determining grades. Graded seeds are essential for orderly marketing and are adopted by both sellers and buyers to determine price.

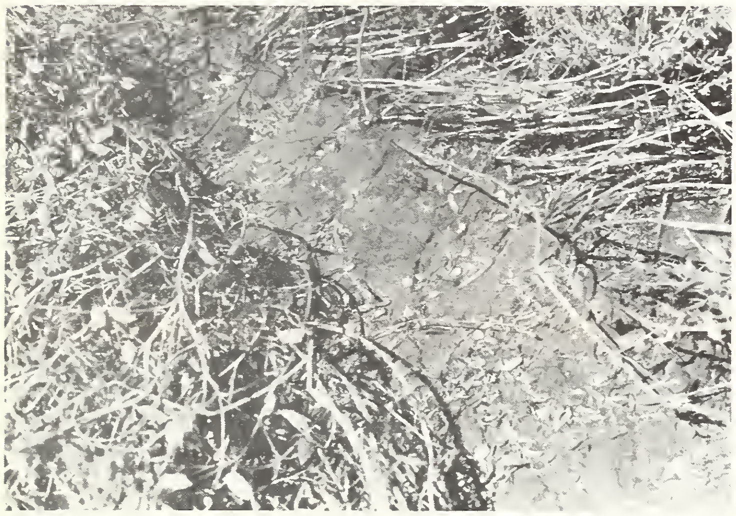

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Figure 6.—Loss of lentil seeds from shattered pods (top); hand harvesting a lentil crop by traditional farmers in Syria (middle); and mowing and swathing lentil crops in the Palouse (bottom).

The outlook in international markets for U.S. lentils seems to be excellent. We have already discussed some trends in production (tables 4, 5, and 6); the world's population continues to increase and many of the larger nations are allocating progressively larger areas of land previously used for lentils (and other traditional pulse crops) to the production of cereal crops (for example, Singh, N., et al. *1978*). Since lentil yields have, in general, not increased significantly in the recent past, these declines in cropped area have not been offset by improved productivity. Thus, demands for lentils in world markets have increased, which directly benefits growers in the Palouse region. Furthermore, the expanding, diversifying, and continually improving advertising and publicity strategy adopted by the industry has ensured that domestic markets have not stagnated. As table 9 shows, lentils contribute significantly not only to farm economics in the Palouse, but also to the U.S. national trade balance (WIDPLC *1978*; Smith *1980*).

Table 9.—*Palouse lentils in domestic and international markets (1979-80)*[1]

Time period	Volume shipped		Commercial value	
	Export	Domestic	Export	Domestic
	$t \times 10^{-3}$		$\$ \times 10^{-6}$	
September 1979 to August 1980	46.5	-	42.3	-
July 1979 to June 1980	-	9.4	-	7.9

[1]Source: Washington and Idaho Dry Pea and Lentil Commissions.

Collaboration, Cooperation, and Communication

Crop improvement in lentils is not just a parochial challenge but one that has now attracted international attention (see appendix A). It seems sensible, logical, and desirable to us that close collaboration, cooperation, and communication be established among the various groups of researchers now charged with regional, national, and international responsibility for improving the productivity of the crop. Researchers should be encouraged to share and exchange their experiences in temperate and more tropical locations; germplasm accessions should be made freely available to others (with appropriate quarantine controls); and breeders, researchers, and commercial producers should foster any opportunity for dialogue. The wishes of consumers (for example, the type, form, color, texture, and taste of product preferred, and the price they are willing to pay for it) must feature strongly in formulating research objectives and breeding strategies. Local preferences are unlikely to be acceptable universally, and market opportunities must be identified and exploited accordingly.

In seeking to review various aspects of the international lentil literature, and to compare data published by different researchers in various countries, we have been frustrated by the range of units used for the same attribute of crop performance: parochial quantities such as bushels, pounds, quintals, acres, fedans and degrees Fahrenheit are no longer acceptable in international scientific literature.

The System International d'Unites (SI), increasingly adopted by members of the scientific community and by the journals in which they publish, has helped to reduce diversity of units and so improve communcation. SI is not without faults (Danloux-Dumesnils *1969*), but it is outstandingly the best system available thus far. Our plea is that in their articles on lentils, researchers should adhere strictly to the conventions of SI and that any symbols used for units and prefixes should be without ambiguity. It is not pedantic to insist on the correct abbreviation—each symbol has only one meaning in SI (Page and Vigoureux *1973*).

While the advantage of SI outweigh its disadvantages (see the excellent discussion by Incoll et al. *1977*), many farmers and others in the lentil industry will be familiar with, and reluctant to change from, more accustomed units. Researchers must seek every opportunity for dialogue with those who actually grow, process, and market the crop. The onus is on those in applied research to become fully conversant with both traditional and SI units.

Palouse farmers recognize the importance of advertising, sales promotion, and research as necessary elements of their overall operations (WIDPLC *1978*). A recently established International Agricultural Research Centre (The International Centre for Agricultural Research in the Dry Areas, based in Syria) has lentil research as one of its prime responsibilities (Darling *1979*; Hawtin, *1979*; Kassam *1981*). An annual newsletter (LENS), first published in 1974, has proved to be an excellent vehicle for improving communications among lentil researchers. Regional programs in many countries (for example, United States, India, Canada, Argentina, Hungary, and Chile) now have strong commitments to lentils. Wild germplasm is being collected and conserved. The first definitive publication (in English) devoted to lentils, which considers all aspects of crop production and improvement (see appendix), has just been published.

These are just some examples from the rapidly changing and expanding lentil scene which, we are confident, will better ensure that many of the gaps in knowledge and understanding will soon be filled to the benefit of producers and consumers of lentils alike. Above all, if we accept that the only valid criterion for judging plant breeding work (fig. 7) is its effect on national or regional food production (Jennings *1974*), then this simple criterion demands collaboration and cooperation among multidisciplinary breeding teams worldwide. The complementary roles of international and national programs for lentil crop improvement cannot be overemphasized if any improvements in farming potential are to be exploited.

BN-49046

BN-49049

Figure 7.—Hybridization of lentils: dehisced anthers and pollen-laden stigma of male parent being brushed against the stigma of an emasculated flower (above), and breeders' replicated field plots from which progeny materials with desirable characters (for example, erect habit, nonlodging, nonshattering pods, and large yield) are selected (below).

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Appendix A

Lentils in the Palouse

Today's growers recognize the importance of advertising, sales promotion, and research as necessary elements of their overall operations. New markets must be created for the expanding industry. Consumer confidence in the product must be won before it can be successful, and constant improvements in quality are necessary to meet competition and the changing needs of today's markets.

To achieve these objectives, Palouse growers created the Idaho and Washington Dry Pea and Lentil Commissions, which began operations in July 1965 These commissions jointly provide a source of funds and an organization with a professional staff to administer their programs. Each commission's activities are directed by a board composed of nine members, representing local producers and processors.

Contact:

H. Blain
Chief Administrator
Washington and Idaho Dry Pea and Lentil Commissions
State Line Office
P.O. Box 8566
Moscow, Idaho 83843, USA

Lentils Elsewhere

The International Centre for Agricultural Research in the Dry Areas (ICARDA) is a member of the world network of International Agricultural Research Centres. The institute has a world mandate for the improvement of lentil and barley crops and of the agricultural systems in which they are grown and a joint mandate (with International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India) for chickpeas.

Contact:

G. C. Hawtin
Leader, Legume Improvement Program
ICARDA
P.O. Box 5466
Aleppo, Syria

Lentil Experimental News Service (LENS)

A joint venture between the Lentil Research Association (LRA) and the Crop Development Centre, University of Saskatchewan. Canada, aimed at improving communications among lentil researchers throughout the world. Membership in LRA is open to all and for a nominal subscription ($2 per annum in 1981) subscribers will receive, and can contribute to, the current issues of LENS.

Contact:

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(Secretary and Coeditor)
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Legume Breeding and Production
Washington State University
Pullman, Washington 99164, USA

Proceedings: First International Seminar on Lentils

The book entitled "Lentils" is the outcome of a seminar conceived, organized, and sponsored by ICARDA and held in Aleppo, Syria, in 1979. It is not merely the proceedings of a seminar but an independent reference work that will be invaluable to research scientists and all others with an interest in the production and processing of lentils. Leadings scientists from many countries of the world have contributed to make this the first authoritative reference book on lentils in the English language. Subjects covered range from the origin, domestication, and taxonomy of lentils, to the quality and processing of the seed, production yields, and international trade.

The book is fully indexed and well illustrated by photographs and line drawings; 244x187 mm, hard back, approximately 250 p., February 1981. ISBN 0-85198-475-4.

Order from:

Commonwealth Agricultural Bureaux,
Farnham House, Farnham Royal, Slough, SL2 3BN, England

Federal Research (USDA)

A program of research with a regional mandate for breeding and production of edible grain legumes, including lentils.

Contact:

F. J. Muehlbauer

National Research (Elsewhere):

G. C. Hawtin and A. E. Slinkard are likely to be best placed to advise on particular request for contents in lentil-producing countries such as those listed in table 1.

Appendix B: Conversion Factors

Factors for the Conversion of Imperial, USA, and Other Units into Metric Units

Imperial, U.S.A., or other	*Metric*
1 inch	= 2.54 centimeters (cm) = 25.4 millimeters (mm)
1 foot (ft)	= 30.5 cm (= 305 mm)
1 yard (yd) (= 3 ft)	= 0.914 meter (m) = 91.4 cm
1 mile (=1,760 yd)	= 1.61 kilometers (km) = 1610 m
1 square inch (in^2)	= 6.5 square cm (cm^2) = 645 mm^2
1 square foot (ft^2)	= 0.093 square m (m^2) = 930 cm^2
1 square yard (yd^2)	= 0.836 m^2
1 acre (= 4,840 yd^2)	= 0.405 hectare (ha) = 4047 m^2
1 square mile (mi^2) (=640 acres)	= 2.59 km^2
1 ounce (oz)	= 28.4 grams (g)
1 pound (lb) (= 16 oz)	= 0.454 kilogram (kg) = 1000 g
1 hundredweight (cwt) (=112 lb)	= 50.8 kg
1 long ton (= 2,240 lb) (=20 cwt)	= 1016 kg = 1.016 metric tons (tonnes) (t)
1 short ton (= 2,000 lb)	= 907 kg = 0.907 metric ton (tonnes) (t)
1 pint (= 1.2 U.S. pints)	= 0.568 liter (L) (U.S. = 0.473 L)
1 gallon (gal) (= 8 imperial pints)	= 4.55 L (U.S. = 3.79 L)
1 fluid ounce (=0.05 imperial pint)	= 0.0284 L = 28.4 milliliters (ml) (U.S. = 29.6 ml)
1 cubic foot (ft^3)	= 28.3 L
1 mile per hour (mph)	= 1.61 kmh^{-1}
1 quintal	= 100 kg
1 bushel (lentils) (bu)	= 69 lb = 27.24 kg
1 fedan	= 0.42 ha (=4200 m^2)
1 donum (= 1 decar)	= 0.1 ha (=1000 m^2)
1 ar (= 0.1 decar)	= 0.01 ha (= 100 m^2)

Factors for the Conversion of Metric to Imperial, USA, or Other Units

Metric	*Imperial, U.S.A., or other*
1 centimeter (cm)	= 0.394 inch = 0.033 ft
1 meter (m)	= 1.094 yd
1 square meter (m^2)	= 1.196 yd^2
1 hectare (ha)	= 2.471 acre
1 gram (g)	= 0.0353 oz

Factors for the Conversion of Imperial, USA, or Other Units—Continued

Metric	*Imperial, U.S.A., or other*
1 kilogram (kg)	= 2.21 lb = 0.0197 cwt = 0.00098 ton
1 tonne (metric ton) (t)	= 0.9842 ton
1 liter (L)	= 1.76 pints = 0.22 gal (U.S. = 2.11 pints = 0.26 gal)
1 L (= 1000 milliliters) (ml)	= 35.2 fluid ounces = 0.0353 ft^3 (U.S. = 33.8 fluid ounces = 0.0339 ft^3)
1 kg (= 1000 g)	= 0.01 quintal = 0.037 bu (lentils)
1 ha (= 1000 m^2)	= 2.38 fedan = 10 donum (decar) = 100 ar

Useful Conversions

The following conversions may be especially useful:

To convert	*Multiply by*	*To convert*	*Multiply by*
oz $acre^{-1}$ to g ha^{-1}	70.06	g ha^{-1} to oz $acre^{-1}$	0.01427
lb $acre^{-1}$ to kg ha^{-1}	1.121	kg ha^{-1} to lb $acre^{-1}$	.8921
cwt $acre^{-1}$ to kg ha^{-1}	125.5	kg ha^{-1} to cwt $acre^{-1}$	.007966
cwt $acre^{-1}$ to t ha^{-1}	.1255	t ha^{-1} to cwt $acre^{-1}$	7.966
ton $acre^{-1}$ to kg ha^{-1}	2511	kg ha^{-1} to ton $acre^{-1}$	.0003983
ton $acre^{-1}$ to t ha^{-1}	2.511	t ha^{-1} to ton $acre^{-1}$	.3983
gal $acre^{-1}$ to L ha^{-1}	11.233	L ha^{-1} to gal $acre^{-1}$	.08902

The following factors are accurate to about 2 parts in 100:

1 lb $acre^{-1}$ = 1.1 kg ha^{-1}
1 gal $acre^{-1}$ = 11 Liters ha^{-1}
1 ton $acre^{-1}$ = 2.5 t ha^{-1}

In general reading, there will be no great inaccuracy in regarding:

1 lb = 0.5 kg
1 lb $acre^{-1}$ = 1 kg ha^{-1}

Temperatures

To convert °F into °C, substract 32 and multiply by 5/9 (0.556).
To convert °C into °F, multiply 9/5 (1/8) and add 32.

Plant Nutrients

Plant nutrients are best stated in terms of amounts of the elements (P, K, Na, Ca, Mg, S); the old "oxide" terminology (P_2O_5, K_2O, Na_2O, CaO, MgO, SO_3) is still used in work involving fertilizers and liming since regulations require statements of these oxides.
For quick conversions (accurate to within 2 percent), the following factors may be used:

2 1/3 × P = P_2O_5	3/7 × P_2O_5 = P
1 1/5 × K = K_2O	5/6 × K_2O = K
1 2/5 × Ca = CaO	7/10 × CaO = Ca
1 2/3 × Mg = MgO	3/5 × MgO = Mg

For accurate conversions:

To convert	*Multiply by*	*To convert*	*Mulitply by*
P_2O_5	0.4364	P to P_2O_5	2.2915
K_2O to K	.8301	K to K_2O	1.2047
CaO to Ca	.7146	Ca to CaO	1.3994
MgO to Mg	.6031	Mg to MgO	1.6581

Appendix C: Pesticide Designations

Trade name	*Common name*	*Chemical name*
Captan	captan	N-[(trichloromethyl)thio]-4 cyclo-hexane-1, 2-dicarboximide
Far-go or Avadex BW	triallate	S-(2, 3, 3-trichloroallyl)diisopropyl thiocarbamate
Avadex	dialiate	S-(2, 3,-dichloroallyl)diisopropyl thiocarbamate
Carbyne	barban	4-chloro-2-butynyl-m-chlorocarbaminate
Sencor or Lexone	metribuzin	4-amino-6-1-(1,1-dimethyl)-3-(meyhylthio) 1, 2, 4-triazine-5(4H)-one
Premerge 3	dinoseb amine	2-sec-butyl-4, 6-dinitrophenol
Several	2, 4-D	(2, 4-dichlorophenoxy) acetic acid
Disyston	disulfoton	0, 0-diethyl S-[2-(ethylthio)ethyl] phosphorodithioate
Cygon	dimethoate	0, 0-dimethyl S-(N-methylcarbamoyl-methyl) phosphorodithioate
gamma BHC	lindane	1, 2, 3, 4, 5, 6-hexachlorocyclohexane, gamma isomer of not less than 99 percent purity
Cythion	malathion	0, 0-dimethyl phosphorodithioate of diethyl mercaptosuccinate

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